# Role of Tabular Alumina as a suitable aggregate for emerging applications – focus on dry ramming mix

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## 1. Introduction

High alumina refractories in the iron and steel industry were thoroughly discussed in 1990 by authors from Europe, Japan, and America [1-3]. Many changes took place over the past 20 years. The on-going demand of clean steel production technology requires improved high alumina refractory materials. New high alumina raw materials and refractories have been developed and are becoming benchmark product in the industry day by day in several applications. It has been already proven with numerous experimental and live data and years of sustained businesses that synthetic tabular aluminas and sintered Magnesium aluminate spinels, in combination with pure, performing reactive aluminas and calcium aluminate cements excel in their performances in applications like the castables for well block & purging plugs, ladle lining, tabular alumina-zirconia-carbon slide gate refractories, tabular alumina-magnesia-carbon resin bonded brick, >95% Al2O3 bricks and so on. We know that in the above applications, tabular alumina and spinel based refractory products outperform fused products (white or brown fused alumina/ fused spinel) because of microstructural advantages and associated benefits and consistency exhibited by synthetically sintered products over fused ones. Parameters like uniformity of chemical purity, homogeneity of particle size distribution (PSD), closed porosity and high toughness impart superior properties in refractories with better rheology, hot strengths, thermal stability, thermal spalling, abrasion and corrosion resistances. In this study, we attempted to explore the role and functions of such synthetic aluminas in few other applications, where the benefits of using tabular alumina and associated synthetic products like sintered spinels and reactives would further drive the performances. The applications explored are the tabular alumina-SiC-carbon containing blast furnace runner masses, tabular alumina and synthetic spinel containing Al2O3-spinel fired brick for steel ladle lining, tabular alumina-carbon black refractories for continuous casting applications and alumina-spinel neutral ramming mass for induction furnace in foundry industry. Some of the key parameters required for these applications are evaluated through experiments conducted at Almatis application laboratories. This paper studies the comparative properties of these emerging application through experimental results and analysis, where the superior performance benefit as well as cost effectiveness of tabular alumina and synthetic spinel in such applications vis-à-vis commonly conceived ingredients like fused aluminas are highlighted. The results provide a choice to the refractory manufacturers who are venturing into these emerging performances and designs, to investigate locally available tabular alumina in place of traditional fused grits and establish the laboratory based results into business growth. Based on the laboratory experimental data, the paper opens up further the scope of more detailed investigations and studies in the fields of ladle and continuous casting refractories, in an attempt to enhance the value of the refractories in such applications.

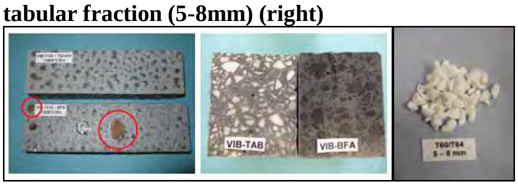
## 2. Blast furnace trough castable

LC and ULC castables with typically 70-85 % $Al_2O_3$ and 10-20 % SiC are used for the wear lining in blast furnace main trough. BFA is the commonly used aggregate for these castables. The specific refractory consumption in modern larger blast furnaces is higher than the earlier smaller furnaces. This is mainly due to higher structural erosion in bigger furnaces due to higher tapping temperatures and the dimension of the runner´s cross section is not increased in proportion to the amount of iron produced per minute. Tabular alumina has been reported to provide advantages under such demanding conditions both in performance and cost. Bars of different aggregates (BFA and tabular) were tested after firing at 1500°C in air. No differences can be found in oxidation or strength of the castables. The BFA test bar shows molten spots at the surface due to locally concentrated impurities, which are mainly Fe and Ti based (fig 1). The cut surfaces show some larger cracks in BFA test bar but not in tabular alumina bar (fig 1). Like WFA, BFA is produced in batch fusion process and thus homogeneity of chemistry throughout a fused block depends on the proper material selection for fusion and materials selection after crushing. Whereas tabular alumina production process could be described as a continuous ceramic process which involves fine milling of a single source calcined alumina feedstock, ball forming, drying, sintering and thus leads to a very homogeneous product in all fractions too. Blast furnace runner castables are complex products often containing up to 20 constituents. The consistent chemical properties of all the fractions in sintered tabular aggregates provide a better alternative to the BFA fractions chemistry inconsistency issues. Table 1 below shows typical chemical analysis of BFA as well as WFA aggregate materials compared to tabular alumina T60/T64.

**Tab. 1 Analysis of different alumina aggregates**

| | **BFA** | **WFA** | **T60/T64** |
|---|---|---|---|
| Al2O3% | 94-96 | 99-99.5 | 99.6 |
| SiO2% | 0.8-1.5 | 0.02-0.05 | 0.01 |
| TiO2% | 1.5-2.5 | 0.01-0.05 | 0.002 |
| Fe2O3% | 0.15-0.5 | 0.08-0.1 | 0.04 |
| Alkaline & A Earths% | 0.6-0.7 | 0.35-0.45 | 0.3-0.4 |
| Bulk den. g/cc | 3.8-3.9 | 3.5-3.9 | 3.55 |
| App porosity % | 1.5 | 5-8 | 1.5 |
| water absorption % | 0.5 | 2-3 | 0.5 |

**Fig. 1 BF runner castable test bars after firing at 1500°C in air. Test bar surface (Tabular left up, BFA left down) and cut surface (middle). Coarse tabular fraction (5-8mm) (right)**

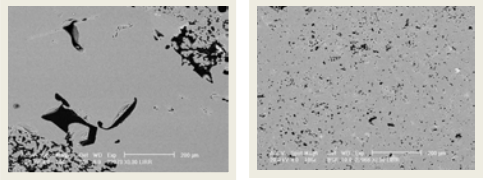


The quality consistency of synthetic aggregate tabular alumina from batch to batch and for years have manifested in terms of superior performance consistency and reliability of BF runner castables for large blast furnaces. This is what an iron and steel plant needs – reliability and performance – which is not possible through direct mineral to fusion based products like BFA, no matter how pure the bauxite ore is! The fluctuations of particle size distribution of fine fractions are of significant concern in fused alumina compared to tabular alumina. Additionally, the higher density of BFA (typically 3.8 g/cc) when compared to tabular alumina (typically 3.55 g/cc) shows in a 5-6% higher density in the castable. Thus quantity of material required for a lining is 5-6% lower when tabular alumina is used as aggregate. This should also be considered when an economic comparison is made between both concepts. Additionally, use of coarse tabular fraction (5-8mm and 5-10mm) (figure 1 above) fractions add further mechanical strengths and erosion resistance to the above mentioned advantages and makes tabular based trough castable most suitable for this application and industrial tests are successful with predictable, reliable and better performance.

## 3. ULC and LC castables for PCPF shapes

The rheological behaviour of tabular alumina containing castable differs significantly from a WFA body due to inherent porosity distribution and grain shape differences. Tabular alumina is produced in a sintered route and the product is having a characteristic microstructure of large tablet shaped crystals with very small sized (<10 µm) closed pores. Because of these large numbers of closed pores, the bulk density is lower than fused products while the open porosity is only 1.5%. This accounts for very low water absorption for tabular alumina (table 1). Whereas WFA is manufactured by fusion process which provides 2-3 times higher open porosity in the body due to fast cooling cracks of the fused blocks. The fused alumina structure is devoid of closed pores and hence the bulk density is higher (fig 2). This is why the WFA material shows 2-3% higher water absorption compared to tabular alumina.

**Fig. 2 Microstructure of WFA (left), Tabular (right)**



Because of the above microstructural difference, if a pure vibrating LC castable with WFA requires 4.8% water to get 100% vibration flowability after 30 minutes, the same castable of tabular alumina (only by changing the WFA to tabular alumina) can provide exactly similar flowability after 30 minutes with just 3.8% water addition. This 1% lower water demand in castable ultimately results to about 3% lower apparent porosity in cast bodies with tabular alumina resulting in higher cold and hot strengths. In addition, the abnormal and unpredicted distribution of impurities (primarily Na2O - Beta alumina) in the finer fractions in fused alumina product is also significant reason for higher corrosion and lower hot strengths compared to tabular bodies, which has uniform distribution of soda across coarser to finer fractions. For the above reasons, tabular alumina is always preferred in performances with stringent and highly safety prone applications like seating block and well block, porous plug and nozzles, electrode delta and other ladle pre-cast, pre-fired (PCPF) units like bottom impact pad, etc (fig 3).

**Fig. 3 Typical application of tabular alumina containing castable (left to right) DC EAF delta, well block, porous plug**

### 4. Sliding gate refractories

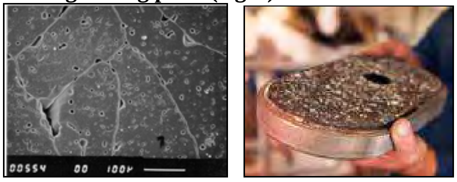
Table 2 shows tabular alumina grains as a synthetic raw material produced in a continuous sintering process, and bearing lower apparent specific gravity, thus resulting in significantly higher thermal spalling resistance than WFA and BFA. As explained earlier, the distribution of tabular alumina microstructure (fig 2) helps to prevent slag infiltration in the sliding plates to provide better erosion resistance. The very high bulk density and relatively dense large crystals of WFA impart brittleness in the white fused alumina containing bodies where the grains are displaced in continuous surface interaction resulting in lower abrasion resistance. But tabular alumina grains with large uniform crystals and closed porosity and comparatively lower bulk density acting as crack arrestors, tolerate increased toughness and thus exhibit higher abrasion resistance index, even at elevated temperature. For this reason, the lower abrasion resistance characteristic of a fused grain is utilized in designing an abrasive wheel where brittle behaviour and generation of new surfaces are desired for superior cutting effect. Additionally, the lower amount of impurities (table 1) in tabular alumina, help to achieve higher hot strength in final refractory body compared to a WFA containing body. The performance advantage of tabular alumina lies primarily in its thermal spalling resistance, abrasion resistance and erosion resistance over alternative options like WFA or BFA.

**Tab 2: Advantage of Tabular alumina over other aggregates in thermal spalling resistance**

| Grain (5 mm) Physical Properties of $Al_2O_3$ Aggregates | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Al_2O_3$ Aggregate | Thermal spalling resistance % undamaged, Cycles 20°C - 1300°C - 20°C | | | Grain crushing strength after thermal shocking [kg], Cycles 20°C - 1300°C - 20°C | | | Grain strength breaking load [kg] | Apparent specific gravity [g/cm$^3$] |
| | 10 cycyles | 20 cycles | 30 cycles | 10 cycyles | 20 cycles | 30 cycles | | |
| Tabular Alumina | **95** | **87** | **73** | **170** | **118** | **80** | **296** | 3.66 |
| White Fused | 68 | 19 | 0 | 21 | 4 | 0 | 105 | 3.89 |
| Brown Fused | 62 | 10 | 0 | 38 | 5 | 0 | 195 | 3.97 |
| Spinel | **82** | **53** | **20** | **43** | **30** | **12** | **242** | 3.26 |

*(Method of evaluation: +5mm grains of each product are subjected to thermal cycles & % undamaged particles are noted by sieving in 5mm screens. Grain strength is measured by impact load on a single grain; load required to disintegrate the same is measured.)*

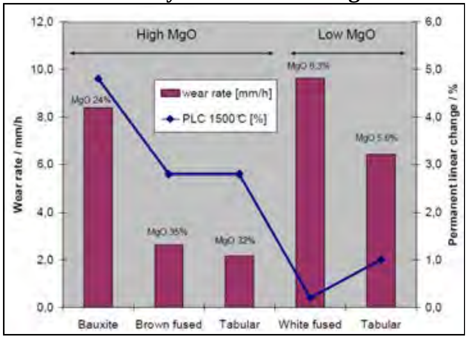
**Fig. 4 SEM of thermally etched at 1500˚C, polished section of Tabular alumina (left), tabular alumina containing sliding plate (right)**



### 5. Alumina magnesia carbon bricks

Alumina magnesia carbon brick with tabular alumina proves its suitability over fused alumina in steel ladle due to chemical consistency of different fractions of tabular alumina. Since tabular alumina is more reactive in nature than fused alumina, proper selection of fractions and amounts are needed to obtain only just optimum expansions required for joint tightening. An uncontrolled expansion may lead to structural spalling and low performance. While using tabular alumina, a proper material designing with less MgO is sufficient to develop the required spinel formation to provide higher slag corrosion resistance. This spinelization also results in densification at the hot brick surface and seals the brick joints against low viscosity slag (containing $CaF_2$ and/or MnO). Properly designed AMC bricks with tabular alumina give predicted and uniform service life in steel ladles especially in demanding areas such as the bottom where they show higher creep resistance when compared to fused aggregates.

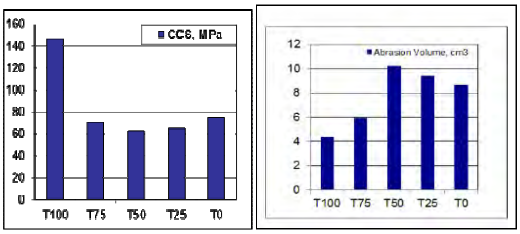
**Fig. 9 Induction furnace slag corrosion at 1650°C/ 2hr with slag of C/A=1 & $CaF_2$. 1500°C PLC of AMC bricks vary with different MgO content**



## 6. High alumina bricks

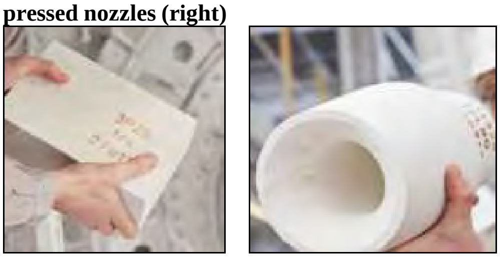
High purity corundum brick is widely used in oil cracking units, coal gasifiers, carbon black and other industrial furnaces where critical properties are chemical corrosion resistancce, mechanical abrasion restsiance and thermo-mechanical properties. It is seen that 100% tabular alumina containing bodies (T100) show much higher density, lower apparent porosity, higher compressive and tensile strengths than 100% WFA (T0) containing bodies or their other combinations (figure 5). This is due to the higher sinter reactivity of tabular alumina at high temperatures in addition to evenly distributed small closed pores compared to large single pores and higher open porosity of WFA. This also provides an opportunity for tabular alumina bricks to fire at a slightly reduced temperature (fuel saving) to achieve similar porosity, density and strength patterns to WFA containing bricks. Tabular alumina based corundum brick outperform WFA based brick on corrosion due to porosity difference and fluctuating impurities like Na2O in WFA. The superior abrasion resistance exhibited by a 100% tabular alumina based corundum brick is shown in figure 5 vis-à-vis 100% WFA based brick.

**Fig.5: Mechanical strength & abrasion resistance differences among Tabular Alumina and WFA based corundum brick (ref 4: testing at LIRR China)**



*(T100 means 100% tabular and T0 means 100%WFA)*

**Fig. 5 Typical application of tabular alumina containing products: corundum bricks (left), pressed nozzles (right)**



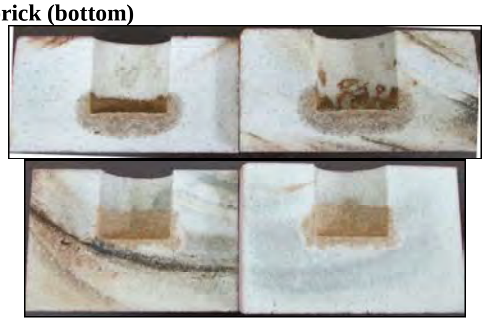
## 7. Alumina-spinel fired brick

With the growing need of advanced metallurgy for ultralow carbon and automobile grade of steels, there is increasing need of low carbon or carbon free refractory lining in steel ladle walls and high alumina or alumina-spinel fired brick became a necessity to meet the refractory demand. Generally, >95% high alumina brick was the only option for carbon free bricks to be used in steel ladle walls but for those grades of steel as well as very corrosive slags (C/S=1.5, 5% CaF2, 2% MnO2) and in absence of monolithic ladle lining in India, there was a need of better quality fired brick. The development of fired alumina-spinel brick since last few years gave enormous benefits to the end users. The lining life has increased significantly due to much superior corrosion resistance and thermal spalling resistance compared to conventional 95-99% Al2O3 brick. Alumina-rich, pre-reacted sintered spinel AR78 has the capability to absorb FeO or MnO from corrosive slag within the free vacancies in its crystal structure. Thus slag viscosity comes down and retards slag infiltration in the alumina spinel brick. Also, the chemical purity of both alumina and spinel fractions are very essential as it is seen in the Tata (previously Corus) steelworks in Ijmuiden, Netherlands that a fired alumina spinel brick with 1% $SiO_2$ achieved only 40% of the life achieved with a fired alumina spinel brick with 0.1% $SiO_2$. This again signifies the benefit of very low impurity containing tabular alumina and synthetic spinel AR78 compared to their counterparts WFA and fused spinel having higher amounts of impurities. The basic differences of porosity distribution of fused and sintered processes discussed earlier explains the advantage of spalling and corrosion resistance for fired tabular alumina-synthetic spinel brick over WFA-fused spinel brick. For the end users, the newly developed brick not only helps for lining life enhancement but also avoids carbon pick-up in steel from graphite containing carbon bonded basic bricks, reduces temperature drop in the metal bath and prevents odour/ fume generation during preheating. At Almatis laboratory, the essential parameters of such bricks are compared with that of traditional high alumina bricks and the substantial corrosion resistance benefit is depicted in below illustration (table 3, figure 10).

**Tab 3: Properties of fired Tabular alumina-synthetic spinel and 99% alumina bricks**

| | 99% Al2O3 | Al2O3-Spinel |
|---|---|---|
| App porosity% | 16 | 18 |
| HMOR (MPa) | 6.2 | 5.8 |
| Spalling (cycle) | 8 | 12 |
| Corrosion (mm) Si-killed slag | 5 | 0.5 |
| Penetration (mm) Si killed slag | 15 | 5 |

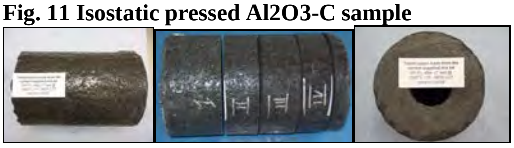
**Fig. 10 Cup slag corrosion at 1500°C/ 5hr with Si-killed slag (C/S=1.67, 5%Al2O3, 5%CaF2, 2%MnO2)- 99%Al2O3 brick (top), Al2O3-spinel brick (bottom)**



## 8. CC nozzles

In general, WFA or BFA grit sizes are used to manufacture chemically bonded and later fired Al2O3-C nozzles. Primarily, the reason of using fused alumina in those products is primarily due to historical reasons and lack of initiative to experiment with alternative compositions. In parallel, hesitation persists for changing to tabular alumina aggregate as product usage is very sensitive and the end performance changes for many metallurgical process variations where root cause analysis could not be justified commonly. As it is seen in different refractory application advantages of tabular alumina over fused alumina (such as better corrosion resistance due to small sized closed pores and chemical purity, superior spalling resistance due to sintering route production compared to fused route, higher hot strength due to low impurity etc), small laboratory trials were carried out with the idea to evaluate the benefits of tabular alumina in Al2O3-C nozzle manufacturing. Here, isostatic pressed Al2O3-C pieces of 130mm outer diameter were subjected to thermal shock testing and afterwards were cut at different levels (figure 11) and tests were carried out to compare microscopy, porosity, density and water absorption of conventional WFA containing nozzle pieces vis-à-vis tabular alumina containing nozzle pieces (table 4).

**Fig. 11 Isostatic pressed Al2O3-C sample**



**Tab 4: Properties of Al2O3-C nozzle with different alumina aggregate**

| | WFA in aggregate | Tabular alumina in aggregate |
|---|---|---|
| App porosity % | 23.5-25.1 | 18.6-20.3 |
| Bulk density g/cc | 2.30-2.33 | 2.40-2.42 |
| Water absorpn. % | 10-11 | 7-8 |
| Thermal spalling cycle | 9 | 7 |

The normal microscopic observations indicate proper bonding of tabular alumina fractions similar to WFA containing body (figure 12) whereas higher magnification indicates that tabular alumina containing sample should have better thermal spalling resistance due to tabular alumina's small sized closed pores in tabular alumina). But the test results indicated higher thermal spalling resistance for WFA containing sample.

**Fig 12 Normal magnification microscopy of isostatic pressed test pieces: Tabular (left), WFA (right) containing**

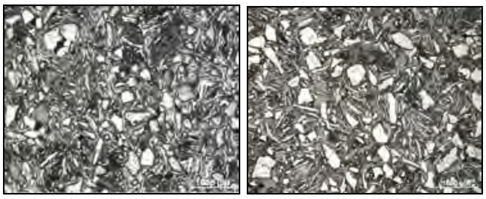
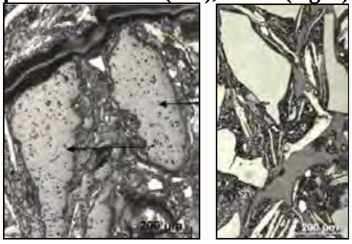


**Fig 13 Higher magnification microscopy of test pieces: Tabular (left), WFA (right) containing**



Such unexpected difference in spalling resistance is due to the greater densification (2.40 compared to 2.30) and therefore reduced open porosity (about 5%) in the microstructure of the tabular alumina containing sample compared to WFA containing sample. Tabular alumina has bulk density of about 3.55g/cc and WFA of about 3.7 g/cc. Thus same weight of tabular alumina will ideally fill a higher volume when compared to WFA. As the isostatic nozzle pressing (volume driven) was carried out without adjustments in the tabular alumina sample weight, a higher densification of the microstructure has resulted and subsequently lowered thermal spalling resistance of tabular alumina sample compared to WFA sample. But this clearly indicates that if mix loading adjustments are carried out, and the matrix porosity is maintained around 4-5% higher than obtained in the above experiment, an equivalent or better (considering chemical purity) isostatic pressed Al2O3-C nozzle can be prepared using Tyler mesh sized homogeneous tabular alumina fractions in aggregate compared to grit sized WFA. Probable quantity of tabular alumina material required for a single isostatically pressed piece would be 5-6% lower than WFA is used. This is also to be considered when any economic comparison is made between both concepts.

## 9. Dry vibratable mass

Dry vibratable mass or dry ramming mass, usually called DVM or DRM, are dry refractory mixes installed by ramming in various types of induction furnaces for foundry industries. The continuously increasing demand of high quality alloy steel casting in induction furnace route calls for high casting temperature (up to 1750˚C) and longer residence time (up to 5-6 hours). Thus there was a requirement to change the refractory type from conventionally used silica or magnesia dry mixes to neutral alumina mixes. The further metallurgical demand resulting higher corrosion by more aggressive slag has resulted in the development of spinel forming alumina DVM. The techno-commercial benefits of these concepts are shown in table 5 below whereas industrial studies showed significant service life increase by when pure alumina DVM is modified to alumina-spinel forming DVM.

**Tab 5: Comparison of different lining concepts - used for Dry Vibratable Mass**

| Properties | Silica | Magnesia | Alumina | Alumina-Spinel |
|---|---|---|---|---|
| Resistance to thermal shock | ++ | -- | + | ++ |
| Resistance to acidic slag | ++ | -- | + | ++ |
| Resistance to basic slag | - | ++ | + | ++ |
| Resistance to abrasion | - | + | ++ | ++ |
| Price | ++ | + | - | - |
| EHS | -- | + | + | + |

### 9.1. MgO part in spinel forming alumina DVM

The basic challenge of spinel forming alumina DVM is to accelerate the spinel formation (without too severe spinelization that may lead to expansion crack) during first few batches of production to protect early wear (at pre-spinelization stage). It is established that MgO with bit higher SiO2 and CaO accelerates spinelization to help in early wear resistance but on the other side the amount of liquid phase increases in such mixes and results in lowered refractoriness. Similarly, a finer fraction (means with higher surface area; like -45 micron) of MgO helps in faster spinelization but carries risk of MgO hydration. Thus dead burnt MgO with 97-98% purity and -75 micron size is optimized industrially and selected for the laboratory trials.

### 9.2. Alumina part in spinel forming alumina DVM

Traditionally WFA fractions are used in these mixes. In the present studies, tabular alumina fractions were tried in place of WFA for spinel forming DVM and the techno-commercial pros and cons of both the concepts are reviewed. Commercially available WFA fractions were taken for trials. In parallel, Almatis Falta plant produced equivalent fractions (nearer to the mm sieve opening, as per Tyler standard) of tabular alumina were taken. These tabular alumina fractions are as per Almatis Global PSD parameters. A fixed amount of 7% special calcined alumina and sintering aid was considered based on other trials which are not in the scope of this study. MgO% was varied from 10-12% during the trial to see the expansive characteristic due to spinelization. For getting the proper spinelization kinetics, the ultimate requirement is to achieve required compaction by adjusting the grain size distribution of the final dry mix. This has to be done only by suitable selection of individual fractions and their amounts. It is seen that the commercially used DVMs with WFA fractions are fitting to an Andreasen coefficient of 0.3 for maximum or rather optimum compaction. Thus the different combinations of tabular alumina fractions is also planned to fit 0.3 Andreasen coefficient for achieving similar compaction. These combinations are shown in table 6.

**Fig 14 Rammed cylinder (right) preparation by sand rammer (left)**

### 9.3. Lab trials and results

The formulated dry mass was mixed with green binder and just required water to form rammed cylinder of 50mm dia and 50 mm height by hammering a fixed number of strokes of a 5kg load (figure 14) in sand rammer. Green density and dimension were checked prior to firing the rammed cylinders at muffle furnace at 1600˚C for 3 hrs. Fired cylinders were measured for getting final density and firing expansion (reported as PLC) prior to cold compressive strength testing (results in table 6).

**Tab 6: Different formulation concepts and results**

| Different WFA fractions | Std Set (%) | T60/T64 T60/T64 Tyler fractions | Set-A (%) | Set-B (%) | Set-C (%) |
|---|---|---|---|---|---|
| 0-3 mm | 81 | 6/10 + 8/14 | 32 | 35 | 38 |
| | | 14/28 + 2 special fractions | 33 | 35 | 34 |
| | | -65<br>-325 | 16 | 12 | 11 |
| Special calcine +sintering aid | 7 | | 7 | 7 | 7 |
| MgO | 12 | | 12 | 11 | 10 |
| Rammed d (g/cc) | 2.78-2.82 | | 2.63-2.64 | 2.65-2.66 | 2.66-2.77 |
| Fired d (g/cc) | 2.31-2.35 | | 2.20-2.22 | 2.22-2.24 | 2.24-2.25 |
| CCS (N/mm2) | 9.6-10 | | 6.4-6.5 | 7.6-7.9 | 8.7-9.5 |
| PLC (%) | 5.3-5.5 | | 6.8-7 | 5.7-6 | 5.4-5.5 |

### 9.4. Discussions

#### 9.4.1. Mix rammed density and effect of individual fractions

The industrially used sample is designed with WFA fractions whereas tabular alumina is as per Tyler fractions. Thus the sieve openings (in mm terms) do not match exactly in each fraction. After trying various options, (keeping Andreasen coefficient 0.3) it is seen that by using tabular alumina, it is difficult to achieve rammed density similar to as achieved by using WFA. This is mainly due to the BSG differences among tabular alumina (around 3.55 g/cc) and WFA (around 3.70 g/cc). The difference after firing at 1600˚C is bit lower but cannot be eliminated. The loose and tapped bulk densities (LBD and TBD) of the individual fractions are also checked to see whether those fractions are workable enough to match the required compaction or not. It is found that the tabular alumina fractions match the LBD and TBD values of corresponding WFA fractions (fig 15). Whereas exactly same difference is not seen in rammed density due to the grain shapes after crushing. The overall recipes of the dry masses are formulated as per mix grain size distribution curves of the different sets (fig 16). It shows similar compaction pattern compared to the same of standard set of WFA fractions. The amount of coarser tabular fractions was increased to get higher rammed density whereas fines are reduced to restrict higher spinelization.

**Fig 15 LBD and TBD graphs of WFA and Tabular alumina fractions**

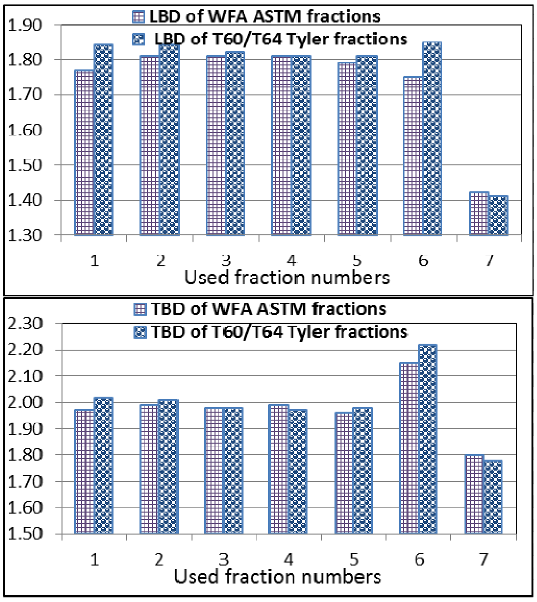
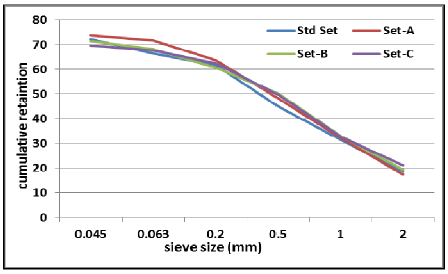


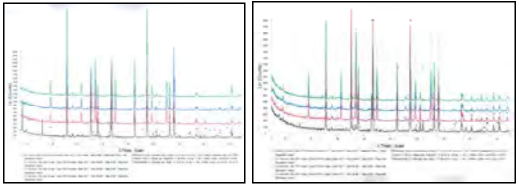
**Fig 16 Grain size distribution chart of different formulations**



## 9.4.2. Spinelization difference in T60/T64 vs. WFA

Set-A was a typical formulation tried to replicate with similar amounts of comparable but not identical fractions used in the standard set of WFA. It is found after firing that expansion is much more (7%) compared to standard 5.5% and thus the corresponding strength in set-A has reduced significantly. This is due to the higher thermal reactivity of tabular alumina with MgO compared to WFA and MgO. Thus the later formulations were with reduced amounts of tabular alumina fines and MgO respectively. The target was to get similar level (to the standard set) of expansion (PLC) as well as fired strength by controlling the total fines distribution and thereby spinelization. It was also assumed that such spinelization in a tabular alumina containing mix will initiate earlier than it happens in a WFA mix. Thus XRD tests of standard formulation and set-C were carried out after firing at different temperatures (fig 17). It is found that at 1000˚C, spinelization didn't occur in both of the mixes. The spinel peaks are much higher with tabular alumina mixes compared to WFA standard mix during 1200-1600˚C. This confirms higher degree of spinelization tendency in tabular containing mix than WFA mix and the necessity of controlling the fines (tabular alumina + MgO) amount in the formulations.

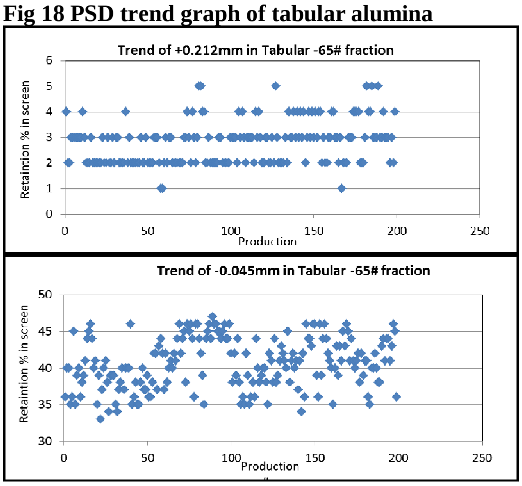
**Fig 17 XRD of DVM fired at 1000/ 1200/ 1400/ 1600 ˚C - having WFA (left) & tabular alumina (right)**



## 9.4.3. Homogeneity of fractions–WFA vs Tabular

It was a traditional myth of PSD homogeneity of WFA sizes and thus WFA selection in DVM. Trend analysis is carried out with all tabular fractions over last 5 years production figures to verify pattern of tabular alumina PSD homogeneity. The below example (fig 18) one such PSD trend data establish that Tyler sized tabular alumina fractions are homogeneous too.

**Fig 18 PSD trend graph of tabular alumina**



## 9.4.4. Field application

Physical or application requirements like flow behaviour, segregation tendency etc of

DVM with tabular alumina are checked by the users during installation and are found satisfactory. The controlled sintering pattern remains in satisfactorily level (fig 19). The other major performance aspect of corrosion resistance is being checked in the application now.

**Fig 19 Controlled sintering pattern in application**

## 10. Conclusion

Tabular alumina continues to prove its superiority over white fused alumina in iron producing applications (i.e. BF trough) to steel casting applications (i.e. CC nozzles) including ladle applications (i.e. well block, porous plug, slide plates, HA brick, Al2O3-Spinel brick, AMC brick etc) as well as foundry applications (i.e spinel forming DVM) due to higher resistances of tabular alumina over white fused alumina on corrosion, spalling, abrasion and thermal stability, cold & hot strengths. Also the homogeneity of PSD and chemical purity provide added value advantages of tabular alumina over WFA. On application sides, continuously growing metallurgical demands are the driving factors for development of better performing alumina refractories with tabular alumina and sintered spinel. High purity synthetic aggregate tabular alumina based raw materials provide the optimum benefits for these demands not only on technical grounds but also in commercial grounds. Having said this, it is also necessary to mention that all these analysis and tests with tabular alumina and sintered spinel are complimented by Almatis store of reactive and calcined aluminas, CA cement and dispersing agents which also played important roles in final findings.

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